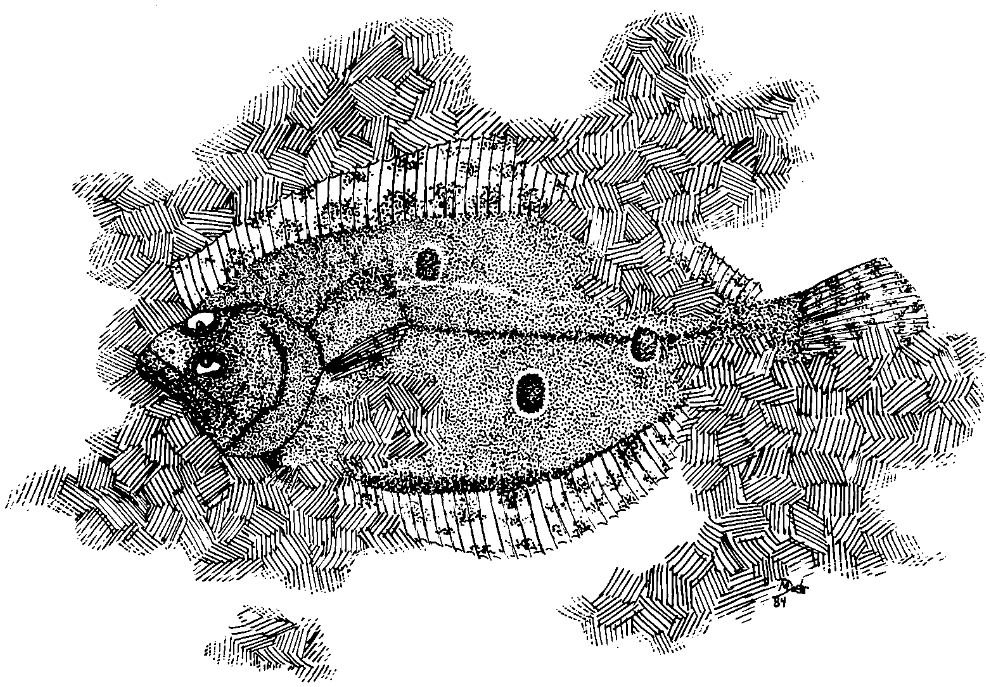
Biological Report 82(10.92)
JUNE 1985

HABITAT SUITABILITY INDEX MODELS: SOUTHERN AND GULF FLOUNDERS



Fish and Wildlife Service

U.S. Department of the Interior

This model is designed to be used by the Division of Ecological Services in conjunction with the Habitat Evaluation Procedures.

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MODEL EVALUATION FORM

Habitat models are designed for a wide variety of planning applications where habitat information is an important consideration in the decision process. It is impossible, however, to develop a model that performs equally well in all situations. Each model is published individually to facilitate updating and reprinting as new information becomes available. Assistance from users and researchers is an important part of the model improvement process. Please complete this form following application or review of the model. Feel free to include additional information that may be of use to either a model developer or model user. We also would appreciate information on model testing, modification, and application, as well as copies of modified models or test results. Please return this form to the following address.

National Coastal Ecosystems Team
U.S. Fish and Wildlife Service
1010 Gause Boulevard
Slidell, LA 70458

Thank you for your assistance.

Species______________ Geographic Location____

Habitat or Cover Type(s)____

Type of Application: Impact Analysis____Management Action Analysis__________
Baseline_______Other____

Variables Measured or Evaluated____
____
____
____

Was the species information useful and accurate? Yes___ No___

If not, what corrections or improvements are needed?_____________________
____
____
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Were the variables and curves clearly defined and useful? Yes____ No____

If not, how were or could they be improved?________________________

Were the techniques suggested for collection of field data:

Appropriate? Yes____ No____
Clearly defined? Yes____ No____
Easily applied? Yes____ No____

If not, what other data collection techniques are needed?________________________

Were the model equations logical? Yes____ No____
Appropriate? Yes____ No____

How were or could they be improved?________________________

Other suggestions for modification or improvement (attach curves, equations, graphs, or other appropriate information)________________________

Additional references or information that should be included in the model:

Model Evaluator or Reviewer____________________ Date____________________

Agency____

Address____

Telephone Number Comm:____________________ FTS____________________

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HABITAT SUITABILITY INDEX MODELS: SOUTHERN AND GULF FLOUNDERS

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Washington, DC 20240

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This report should be cited as:

Enge, K. M., and R. Mulholland. 1985. Habitat suitability index models: southern and gulf flounders. U.S. Fish Wildl. Serv. Biol. Rep. 82(10.92). 25 pp.

PREFACE

The habitat suitability index (HSI) models for the southern and gulf flounders are intended for use in the habitat evaluation procedures (HEP) developed by the U.S. Fish and Wildlife Service (1980) for impact assessment and habitat management. The models were developed from a review and synthesis of existing information and are scaled to produce an index of habitat suitability between 0 (unsuitable habitat) and 1 (optimally suitable habitat). Assumptions involved in developing the HSI models and guidelines for their application, including methods for measuring model variables, are described.

The models are hypotheses of species-habitat relationships, not statements of proven cause and effect. They have not been field-tested. For these reasons, the U.S. Fish and Wildlife Service encourages model users to convey comments and suggestions that may help increase the utility and effectiveness of this habitat-based approach to fish and wildlife management. Please send any comments or suggestions about the HSI models to the following address.

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CONTENTS

ACKNOWLEDGMENTS

The habitat suitability index model for the southern and gulf flounder was reviewed and constructively criticized by George H. Burgess, Jr., Florida State Museum, Gainesville; John H. Finucane, National Marine Fisheries Service, Panama City, Florida; and Elmer J. Gutherz, National Marine Fisheries Service, Pascagoula, Mississippi. Thorough evaluations of model structure and functional relationships were provided by personnel of the U.S. Fish and Wildlife Service's (FWS) National Coastal Ecosystems Team (NCET). Supporting narrative and model reviews also were provided by Regional FWS personnel. Funding for model development and publication was provided by the FWS. The cover illustration was prepared by David S. Maehr, Florida Game and Fresh Water Fish Commission.

SOUTHERN FLOUNDER (*Paralichthys lethostigma*)
GULF FLOUNDER (*Paralichthys albigutta*)

INTRODUCTION

Both the southern and gulf flounders (*Paralichthys lethostigma*, *P. albigutta*) are important commercial and recreational species. Catch statistics for flounder do not differentiate between species; however, southern flounders are more common than gulf flounders except on the gulf coast of Florida (Topp and Hoff 1972). The commercial fishery consists of incidental catches by shrimp trawlers. A total of 853,162 kg (1,880,900 lb) of unclassified flounder worth $572,142 was caught from the Gulf of Mexico in 1976 (U.S. Dep. Commerce 1980). The sport fishery consists of both hook-and-line fishing and gigging.

Distribution

The southern flounder is found along the shores of bays, sounds, and lagoons in comparatively shallow estuarine waters, and occasionally in freshwater, from Albemarle Sound, North Carolina, to northern Mexico (Gutherz 1967). The gulf flounder occurs on the Continental Shelf and in large bays and sounds from Cape Lookout, North Carolina, to the Laguna Madre of southern Texas (Gutherz 1967). Southern flounder are most abundant in the western Gulf of Mexico, whereas gulf flounder are most abundant in Florida (Topp and Hoff 1972). Southern flounder apparently do not live in the area from the Loxahatchee River along the southern Florida Atlantic coast to the Caloosahatchee River along the southern Florida gulf coast.

Life History Overview

Life stages. Developmental stages were defined by Balon (1975) as embryonic, larval, juvenile, and adult. The buoyant, pelagic eggs of *Paralichthys* spp. contain a single oil globule in the yolk (Norman 1934). In the laboratory, eggs of southern flounder hatch in 61 to 76 h (Arnold et al. 1977). The embryo becomes a larva when it switches from exclusively endogenous feeding to exogenous feeding, and the larva becomes a juvenile after metamorphosis produces an adultlike form (Balon 1975). In the laboratory, southern flounder larvae began to metamorphose at 40 to 46 days (8 to 11 mm, 0.3 to 0.4 inch total length, TL) and completed metamorphosis at 50 to 51 days; they then assumed a completely demersal existence (Arnold et al. 1977)[1]. The onset of metamorphosis probably is more strongly related to

[1]All measurements of length in this report are for total length unless otherwise indicated.

size than age; at higher temperatures one would expect metamorphosis at an earlier age but at a similar size (Policansky 1982). Southern flounder are considered juveniles at about 11 to 300 mm (0.4 to 11.8 inches), the size at which females may first become gravid (Stokes 1977; Etzold and Christmas 1979; Nall 1979). Female gulf flounder may become gravid at 145 mm (5.7 inches) (Topp and Hoff 1972).

Growth. Hildebrand and Cable (1930) described the growth of *Paralichthys* spp. collected at Beaufort, North Carolina. Recently hatched flounders (2.5 mm, 0.1 inch) were symmetrical and planktonic. At 7 mm (0.3 inch) TL, larvae lost their symmetry, and their right eye began migrating dorsally. At 11 mm (0.4 inch), the right eye was on the ridge of the head, the body was increasingly compressed, and the left side was more pigmented than the right. At 16 mm (0.6 inch), flounders had a form and shape resembling the adult: the neurocranium had rotated 90°, and both eyes were on the left side of the body. At 26 mm (1 inch), the body's shape was virtually identical to that of an adult, and its pigmentation was restricted almost solely to the left side. By the time a flounder was 77 mm (3 inches) long, its body was completely scaled and had the shape, form, and pigmentation of the adult.

There is some evidence that southern flounder from different areas grow at different rates (Stokes 1977; Etzold and Christmas 1979; Nall 1979), partly due to differences in genetic stock, prey availability, temperature, or salinity (Deubler 1960; Stickney and White 1973; Peters and Kjelson 1975; Laurence 1977).

Nall (1979) noted that the growth of southern flounder from the Florida Panhandle and Alabama was isometric (weight increases directly with length), and the greatest absolute and relative growth occurred in their first 2 years of life, whereas the gulf flounder's growth was allometric (weight increases slower than length). Males of both species grew slower than females, but individuals of equal sizes in both sexes had similar weights (Stokes 1977).

The largest southern flounder collected by Nall (1979) was 492 mm (19.4 inches) standard length (SL) and was 8 years old. Etzold and Christmas (1979) collected 4-year-olds up to 480 mm (18.9 inches) long. Stokes (1977) found 5-year-old females up to 620 mm (24.4 inches) and 3.9 kg (8.6 lb) and 3-year-old male southern flounders up to 320 mm (12.5 inches) and 0.36 kg (0.79 lb). The largest southern flounder on record was 762 mm or 30.0 inches long (Ginsburg 1952).

Gulf flounder are on the average smaller than southern flounder; most gulf flounder are less than 254 mm (10.0 inches) long (Ginsburg 1952). Stokes (1977) collected 3-year-old female gulf flounder up to 420 mm (16.5 inches) and 1.01 kg (2.2 lb) and 2-year-old males up to 290 mm (11.4 inches) and 0.27 kg (0.6 lb). The largest gulf flounder on record was 710 mm or 28.0 inches long and weighed 5 kg or 11 lb (Vick 1964).

Reproduction. In Alabama and northern Florida, Nall (1979) found developing eggs in all female southern flounder over 6 years old but in only 8%, 5%, and 18% of 4-, 5-, and 6-year-olds, respectively. The smallest

maturing southern flounder female Nall (1979) collected was 308 mm (12.1 inches). Southern and gulf flounders from Texas progressed from having no apparent gonads to a maturing stage in their first year to being gravid for the first time at 2 years (Stokes 1977). In Mississippi, southern flounder began to mature as 2-year-olds, and all appeared to be mature at 3 years (Etzold and Christmas 1979). Gonadal examinations of gulf flounder indicated that females mature at about 145 mm (5.7 inches) (Topp and Hoff 1972).

Adult southern and gulf flounders in Texas waters were gravid from mid-September through December (Stokes 1977). Ginsburg (1952) concluded that southern and gulf flounders spawned offshore in the Gulf of Mexico in late fall and early winter and some spawning extended beyond winter. Appearance dates of newly metamorphosed juveniles support the opinion that gulf flounder spawn from November through February in the Gulf of Mexico (Reid 1954; Springer and Woodburn 1960; Topp and Hoff 1972).

In a laboratory environment, male southern flounder began following gravid females 3 weeks before spawning. At midday, spawning females swam to the surface and released eggs that a single attending male immediately fertilized. Each female produced about 40,000 eggs (an average of 9231 per spawn) of which 30% to 50% were fertilized and 6% to 35% of those hatched (Arnold et al. 1977).

Movements. Recently hatched *Paralichthys* spp. larvae (2.5 mm, 0.1 inch) were captured only at sea off the coast of North Carolina (Hildebrand and Cable 1930). Newly metamorphosed juveniles (8 to 16 mm, 0.3 to 0.6 inch) were captured from December through April in estuarine nursery areas, where they remained for 18 to 20 months before moving into the ocean to spawn (Powell and Schwartz 1977). Young *Paralichthys* spp. from 6 to 10 mm (0.2 to 0.4 inch) were collected in North Carolina waters from 24 km (15 mi) offshore to 11 km (7 mi) into estuaries (Hildebrand and Cable 1930). Juvenile flounder from 15 to 100 mm (0.6 to 3.9 inches) appeared to migrate from the main bodies of estuaries into brackish and freshwater creeks and ditches (Hildebrand and Cable 1930). Because southern and gulf flounders have an extended spawning season of variable duration (Stokes 1977) and are serial spawners (Arnold et al. 1977), sizes of juveniles appearing in estuaries may vary among months within a year and between years at the same locality.

Peak appearance of juvenile flounder in estuaries along the Atlantic coast usually occurs at a time when stratification and tidal exchange ratios are at a yearly maximum. Juveniles entering estuaries effectively enter freshwater by apparently "riding out" the ebb tide on the bottom below the saltwater boundary and gradually migrating upstream on the flood tide. Active migration into marshes may occur when juveniles move to the surface at night and are then carried laterally by the flood tide into tidal creeks (Weinstein et al. 1980).

Adult southern and gulf flounders migrate from estuarine to marine water in fall or early winter (Hildebrand and Cable 1930; Simmons and Hoese 1959; Stokes 1977). Adult southern flounder migrate from Texas bays and estuaries into the Gulf of Mexico from September through December; males generally

migrate gulfward earlier than females (Simmons and Hoese 1959; Stokes 1977). Adults in Texas return to estuaries from February through June, although older males may remain in the gulf (Simmons and Hoese 1959; Stokes 1977). In any one year, not all adults migrate from an estuary in fall and early winter; those that remain in winter usually move into deeper estuarine waters in response to low water temperature (Ogren and Brusher 1977; Stokes 1977). Stokes (1977) found that migrating adults were gravid, whereas adults remaining in estuaries in fall were not yet gravid. The migration of adult southern and gulf flounders was generally preceded by a drop in water temperature of 4° to 5° C (7.2° to 9.0° F) (Stokes 1977). Juvenile southern flounder (17 to 54 mm, 0.7 to 2.1 inches) were collected in Texas estuaries from December through May (Gunter 1945; Simmons and Hoese 1959; Arnold et al. 1960; Breuer 1962; Stokes 1977).

Tagged southern flounder showed no consistent pattern of activity between and within Texas bays; distances between points of recapture varied from 0 to 18.2 km (11.3 mi) over a period of 3 to 212 days. The fastest rate of movement was 9.3 km (5.75 mi) in 3 days. A year after being tagged in Aransas Bay, a fish was recovered more than 451 km (280 mi) away in the gulf. Gulf flounder more than 2 or 3 years old probably live exclusively in the gulf (Stokes 1977).

SPECIFIC HABITAT REQUIREMENTS

Adult

Temperature. In gulf coast populations of southern and gulf flounders, adults are offshore in the warmer gulf waters during cooler weather (September through April) and inhabit the warmer estuarine waters in warmer weather (May through August). In a Texas estuary, Gunter (1945) collected southern flounder at temperatures of 9.9° to 30.5° C (49.8° to 86.9° F). In Louisiana estuaries, Perret (1971) collected adult southern flounder at temperatures of 5.0° to 34.9° C (41.0° to 94.8° F), and Barrett et al. (1978) collected southern flounder at 10.4° to 29.8° C (50.7° to 85.6° F). In Florida, Reid (1954) collected gulf flounder in the Cedar Key area at surface temperatures of 8.3° to 30.6° C (46.9° to 87.1° F), and Springer and Woodburn (1960) collected gulf flounder in the Tampa Bay area at 11.2° to 32.5° C (52.2° to 90.5° F). In Aransas Bay, Texas, Stokes (1977) collected both southern and gulf flounders at temperatures of 10.0° to 31.0° C (50.0° to 87.8° F), and adults left the bay for gulf waters during the period when the mean water temperature dropped from 23.0° C (73.4° F) in October to 14.1° C (57.4° F) in December. Of seven peak periods of emigration from Aransas Bay, four occurred when cold fronts reduced water temperatures by 4° to 5° C (7.2° to 9.0° F) (Stokes 1977). Based on findings for other fish species, the upper temperature limit for flounder is assumed to be about 40° C (104° F).

Salinity. Adult southern flounder are highly euryhaline, but adult gulf flounder avoid low salinities. Simmons (1957) collected adult southern and gulf flounders at salinities as high as 60 parts per thousand (ppt). In estuaries, however, adult southern flounder seem to prefer salinities between

5 and 20 ppt (Gunter 1945; Williams and Deubler 1968; Perret and Caillouet 1974; Tarver and Savoie 1976; Stokes 1977; Barrett et al. 1978), while adult gulf flounder seem to prefer salinities higher than 20 ppt (Gunter 1945; Springer and Woodburn 1960; Topp and Hoff 1972). In Florida, Springer and Woodburn (1960) collected gulf flounder from the Tampa Bay area at salinities of 13.7 to 33.7 ppt, with very few taken at salinities less than 20 ppt. Reid (1954) collected gulf flounder from the Cedar Key area at salinities from 17.5 to 31.5 ppt. In Aransas Bay, Texas, southern flounder were taken only at salinities of 6 to 36 ppt and gulf flounder only at salinities averaging over 16 ppt (Stokes 1977). Although 1 of 12 gulf flounder collected by Gunter (1945) in Texas was taken at a salinity of 9.6 ppt, 10 were taken at salinities between 25 and 35 ppt. Gunter (1945) collected various numbers of southern flounder at different salinity ranges: 32 at 0 to 4.9 ppt, 53 at 5.0 to 9.9 ppt, 49 at 10.0 to 14.9 ppt, 56 at 15.0 to 19.9 ppt, 35 at 20.0 to 24.9 ppt, 7 at 25.0 to 29.9 ppt, and 9 at $\geq$ 30.0 ppt. The 801 southern flounder collected by Perret (1971) in Louisiana estuaries were distributed equally over salinities of 0 to > 30 ppt. In the St. Johns River on Florida's Atlantic coast, 13 gulf flounder (51 to 168 mm, 2 to 7 inches SL) were taken at salinities of 7.7 to 28.0 ppt, whereas 94 southern flounder (22 to 311 mm, 0.9 to 12 inches SL) were taken at salinities of 0 to 30.2 ppt (Tagatz 1967). For southern flounder, seasonal changes in osmoregulatory processes correspond to spawning migrations between estuarine and offshore waters (Hickman 1968).

Dissolved oxygen and pH. In Louisiana estuaries, southern flounder were caught at dissolved oxygen concentrations of 4.0 to 10.5 mg/l (Barrett et al. 1978). Although the lower lethal limits of dissolved oxygen for southern and gulf flounders are unknown, an oxygen level of 3.0 mg/l is limiting to other fish species (Hoss and Peters 1976). Limiting dissolved oxygen concentrations are most likely during brief periods in summer when biological and chemical oxygen demands are high and thermal or salinity stratification inhibits mixing of the water column. In Aransas Bay, Texas, southern flounder were caught at pH values from 7.65 to 8.60, and there was no apparent relationship between pH values and flounder distribution and abundance (Stokes 1977).

Depth. Although southern flounder prefer comparatively shallow waters, in the Gulf of Mexico they are commonly caught at depths of 44 m (144 ft) (Hildebrand 1954) and have been caught as deep as 66 m (216 ft) (Stokes 1977). In Aransas Bay, Texas, adult southern flounder were collected mostly along the shore in summer and near a pass leading to the Gulf of Mexico in fall. In winter, nonspawning adults were collected in the deepest water in the middle of the bay (Stokes 1977). Gulf flounder are most frequently collected near the mouths of large estuaries or offshore. While on the Continental Shelf, gulf flounder generally occupy water less than 91 m (300 ft) deep, but may be found as deep as 128 m (420 ft) (Gutherz 1967; Benson 1982).

Substrate. According to Ginsburg (1952), southern flounder prefer mud bottoms and gulf flounder prefer hard or sandy bottoms. Nall (1979) collected 152 southern flounder on mud bottoms, 25 on mud and sand bottoms, and none on sand bottoms. The substrate preference of gulf flounder was not

as definitive as that for southern flounder, but Chi square analysis indicated a significant ($P < 0.05$) relation between bottom type and species (Nall 1979). Only 5 gulf flounder were collected on mud bottoms, whereas 16 were collected on mud and sand bottoms and 12 on sand bottoms (Nall 1979). At two gigging stations in Aransas Bay, Texas, most southern flounder were taken at the nearshore station with the finer sediments, whereas most gulf flounder were taken at the channel station, where sediments were coarser (Stokes 1977).

Although most studies report southern flounder to be most abundant on soft bottoms composed of rich organic mud, clay, or silt, Tabb and Manning (1961) collected southern flounder in southwestern Florida on shell and firm marl bottoms. The identity of the specimens collected by Tabb and Manning (1961), however, was questioned by Topp and Hoff (1972) on the basis of a range map. Dahlberg and Odum (1970) collected southern flounder in Georgia from bays with primarily sand bottoms.

Although gulf flounder are occasionally found on muddy bottoms, they prefer firmer bottoms which may consist of sand, shell, or coral. Springer and Woodburn (1960) collected gulf flounder from all habitats in the Tampa Bay area of Florida except in freshwater or offshore near rocky reefs; however, Moe and Martin (1965) collected a few gulf flounder near offshore reefs.

Apparent differences in substrate preference between the two flounder species may be more an effect of salinity selection than substrate selection since the two species are morphologically similar and prey upon similar food items. Substrate composition varies depending upon volume of freshwater inflow. A high inflow of freshwater into an estuary results in low salinities, and high sediment loads from rivers result in high turbidity and muddy substrates. Estuaries with low freshwater inflow and correspondingly high salinity are usually characterized by low turbidity and firmer substrates.

Vegetation. In the northern gulf, southern flounder have usually been collected both in highly turbid bays with little rooted vegetation and in brackish or saltwater marshes and small tidal creeks dominated by cordgrass (*Spartina alterniflora*), black rush (*Juncus roemerianus*), wiregrass (*Spartina patens*), and threecorner grass (*Scirpus olneyi*) (Reid 1955; Darnell 1958; Fox and White 1969; Perret 1971; Livingston 1976; Subrahmanyam and Coultas 1980). In Aransas Bay, Texas, most southern flounder were gigged at a site where cordgrass lined the shore and extended out into the water; most gulf flounder were gigged at a site with an unvegetated shoreline (Stokes 1977). Near Cedar Key, Florida, most gulf flounder over 70 mm (2.8 inches) long were collected during warm weather from sparsely vegetated channels or coves with muddy sandy bottoms and during cold weather from shallow flats devoid of thick plant growth (Reid 1954). Near Tampa Bay, Florida, gulf flounder appeared to inhabit sandy areas in marine grass beds (Springer and Woodburn 1960), occurring at depths of less than 1.8 m (6 ft) (Goodell and Gorsline 1961).

Food. Southern and gulf flounders are highly predaceous, feeding on both benthic and pelagic fishes and crustaceans. The feeding behavior of

southern flounder is probably similar to that of the summer flounder (*Paralichthys dentatus*), a primarily diurnal feeder that can capture prey equally well on the bottom or in the water column (Olla et al. 1972; Powell and Schwartz 1979). Although flounder may bury their bodies in the sediment, they do not ambush passing prey. Instead they stalk prey on the bottom, striking at speeds of 40 to 50 cm/s (16 to 20 inches/s) (Olla et al. 1972).

Larger southern and gulf flounders tend to prey proportionally more on fish than on other types of prey (Reid 1954; Springer and Woodburn 1960; Topp and Hoff 1972; Stokes 1977; Powell and Schwartz 1979), but often eat penaeid shrimps and portunid crabs (Fox and White 1969; Topp and Hoff 1972; Overstreet and Heard 1982). In southern and gulf flounders over 150 mm (6 inches), fish constituted 70% and 72% of the food items, respectively; penaeid shrimp were the most frequent invertebrates, followed by blue crabs (*Callinectes sapidus*) (Stokes 1977).

Fishes commonly eaten by southern flounder in the Gulf of Mexico include anchovy, (*Anchoa* sp.); mullet (*Mugil* sp.) menhaden (*Brevoortia* sp.), Atlantic croaker, (*Micropogonias undulatus*), pinfish (*Lagodon rhomboides*), and fat sleeper (*Dormitator maculatus*) (Darnell 1958; Fox and White 1969; Stokes 1977; Overstreet and Heard 1982). Relatively minor items in the diet of southern flounder include mysids, gastropods, amphipods, stomatopods, schizopods, clams, and polychaetes (Fox and White 1969; Stokes 1977; Overstreet and Heard 1982).

Fishes commonly eaten by gulf flounder include mullet, menhaden, Atlantic croaker, pinfish, pigfish (*Orthopristis chrysoptera*), longnose killifish (*Fundulus similis*), inshore lizardfish (*Synodus foetens*), pipefish (*Syngnathus* sp.) and anchovy (Reid 1954; Springer and Woodburn 1960; Topp and Hoff 1972; Stokes 1977). The frequency of occurrence of different fish species in the diet of southern flounder, and presumably gulf flounder, depends on seasonal prey abundance; there is no tendency for larger flounders to eat larger prey (Darnell 1958; Fox and White 1969).

Embryo

Since southern and gulf flounders spawn offshore, their embryos are adapted to developing in seawater at salinities of 30 to 35 ppt. Nutrition is endogenous at this stage, so prey availability is not a limiting factor. With the possible exception of thermal shock, predation is probably the only factor limiting the buoyant, planktonic embryos.

Larva

The larval period for the southern flounder, and presumably the gulf flounder, lasts less than 2 months (Arnold et al. 1977) and is spent in marine waters as the fish move with the currents toward inshore waters. The planktonic larvae of marine fish, including flounders, feed on many kinds of organisms, but copepod nauplii predominate in their diets (Houde and Taniguchi 1979). Plankton density is an important determinant of larval survival, and a "critical period" occurs at the onset of exogenous feeding initiation and immediately thereafter (Laurence 1977). Prey concentrations

affect the growth of larval fish, thereby influencing the length of the larval period, during which fish are most vulnerable to predation (Houde and Schekter 1980).

Juvenile

Temperature. Juvenile southern and gulf flounders began immigrating into Texas estuaries from the Gulf of Mexico when the water temperature was as low as 13.8° C (56.8° F), but peak immigration occurred when water temperatures were between 16.0° and 16.2° C (60.8° and 61.2° F) (Stokes 1977). Juvenile southern flounder (17 to 40 mm, 0.7 to 1.6 inches) were captured in Texas estuaries by Gunter (1945) at water temperatures of 14.5° to 21.6° C (58.1° to 70.9° F). Williams and Deubler (1968) reported the capture of juvenile southern and gulf flounders in Atlantic estuaries at water temperatures as low as 2° to 4° C (35.6° to 39.2° F). The optimal temperature for maximum feeding of juvenile southern flounder weighing 0.1 g probably is above 30° C (86° F), the highest temperature tested in the laboratory, and probably decreases as the fish grow. The temperature for maximum conversion efficiency in juvenile southern flounder increases as salinity decreases (Peters and Kjelson 1975). Temperature may indirectly affect flounder survival by determining the length of time they are in a size class that is vulnerable to predation.

Salinity. Although juvenile southern flounder are highly euryhaline and can survive abrupt transfers from seawater (30 ppt) to freshwater (Deubler 1960), young juveniles (< 0.1 g) may not be adapted to low salinities (Stickney and White 1973). Gunter (1945) captured juvenile southern flounder (17 to 40 mm, 0.7 to 1.6 inches) in Texas estuaries at salinities of 19.6 to 30.0 ppt. Stokes (1977) found no young juvenile southern flounder in Texas bay areas with low salinities (10 to 12 ppt) until March; however, these areas were farthest from the gulf. Williams and Deubler (1968) collected juvenile southern flounder (lengths not indicated) in North Carolina estuaries at salinities ranging from 0.2 to 35.0 ppt, but they did not mention sizes. Juvenile gulf flounder were taken only near inlets where salinities were of 22 to 35 ppt (Williams and Deubler 1968). In Pamlico Sound, North Carolina, juvenile gulf flounder were collected at salinities of 6 to 35 ppt but were most abundant near the estuary mouth where salinities were highest (Powell and Schwartz 1977).

Small juvenile southern flounder (<0.1 g) from North Carolina reared in the laboratory at salinities of 0 to 30 ppt showed a positive linear relationship between salinity and growth (Deubler 1960). Larger juveniles (0.5 g) from North Carolina reared in the laboratory at salinities of 5, 15, 25, and 35 ppt grew at about the same rate, until the 10th week when growth leveled off at 35 ppt but continued to increase at 5, 15, and 25 ppt (Stickney and White 1973). This plateau in the growth rate may have occurred because older juveniles are physiologically adapted to lower salinities, since in nature they migrate from seawater to lower salinity estuarine waters by the time they reach 0.5 g (Stickney and White 1973). However, in smaller juveniles (0.15 g) from Georgia reared at salinities of 5, 10, 15, 20, 25,

and 30 ppt, growth rates were highest after 6 weeks at the lowest salinities (5 and 10 ppt) (Stickney and White 1973). In a laboratory study, juvenile southern flounder of the same size from North Carolina and Georgia were held at a salinity of 15 ppt and at equal but increasing water temperatures (Stickney and White 1973). The North Carolina fish attained a mean weight of 0.5 g after 6 weeks, whereas the Georgia ones attained a mean weight of only 0.15 g after 8 weeks (Stickney and White 1973).

Dissolved oxygen. Juvenile southern flounder in a laboratory study gradually withdrew to more highly oxygenated water when the dissolved oxygen concentration fell below 3.7 mg/l (Deubler and Posner 1963). Although general activity increased as water temperatures increased, there was no change in sensitivity to oxygen depletion at temperatures of 6.1°, 14.4°, and 25.3° C (43.0°, 57.9°, and 77.5° F) (Deubler and Posner 1963).

Vegetation. In Texas, juvenile southern flounder were most abundant in the spring at seine stations in estuaries characterized by dense patches (at least 161 culms per 25 square inches) of shoalgrass (*Halodule wrightii*) covering 30% to 60% of the total area (Stokes 1977). Juvenile gulf flounder were taken from areas characterized by dense patches of shoalgrass covering 30% to 60% of the area and from areas where light stands (less than 61 culms per 25 square inches) of shoalgrass occurred in patches covering less than 30% of the area. Juvenile gulf flounder were abundant from January through May on shallow flats in the Cedar Key area of Florida (Reid 1954). No juvenile southern or gulf flounders were captured in Texas bay areas where turbidity exceeded 65 Jackson turbidity units (Stokes 1977).

Food. In the laboratory, newly metamorphosed juvenile southern flounder readily fed on rotifers (*Branchionus plicatilis*) and brine shrimp nauplii (*Artemia* sp.) (Deubler 1958; Lasswell et al. 1977). Juvenile southern flounder (10 to 150 mm, 0.4 to 6 inches) feed primarily on small crustaceans, particularly mysids (Diener et al. 1974; Stokes 1977; Overstreet and Heard 1982). Numerically, 95% of food items in juvenile flounder from Texas were invertebrates, 33% of which were mysids, followed by *Acetes*, *Penaeus*, sergestids, and amphipods (Stokes 1977). Although small fish were minor components of the diets of juvenile southern flounder in gulf estuaries, juveniles (100 to 200 mm, 4 to 8 inches) in Atlantic estuaries selected fish (65% of stomach contents by volume) over mysids (29%) despite the abundance of mysids (Powell and Schwartz 1979). Juvenile gulf flounder feed primarily on small crustaceans, such as penaeid shrimp and amphipods, but may also eat small fishes and marine worms (Reid 1954; Springer and Woodburn 1960; Topp and Hoff 1972). They become more piscivorous after reaching a length of about 45 mm (2 inches). Numerically, 84% of food items in small gulf flounder (10 to 150 mm, 0.4 to 6 inches) from Texas were invertebrates, 57% of which were mysids (Stokes 1977).

HABITAT SUITABILITY INDEX (HSI) MODELS

Model Applicability

The habitat suitability index (HSI) models in this report are developed for application in estuarine habitats of the northern and eastern Gulf of Mexico from Florida to Texas. The models can be used to evaluate habitat for juvenile southern and gulf flounders year-round. The models also evaluate habitat quality for adults while they are in estuaries, primarily from May through August.

Minimum habitat area. Minimum habitat is defined as the contiguous suitable habitat required for a species to live and reproduce. No minimum spatial requirements have been reported for either the southern or gulf flounders, but they do require estuarine areas with open access to offshore areas.

Verification level. The acceptable output of the HSI models is a value between 0 and 1. This value has a positive relation to the carrying capacity for southern or gulf flounders in the estuarine habitat. Sample data sets, which are presented later, were used to verify that HSI's determined with these models were reasonable and acceptable. The southern and gulf flounder HSI models were reviewed and evaluated by these biologists: G. H. Burgess, Jr., Florida State Museum, Gainesville; J. H. Finucane, National Marine Fisheries Service, Panama City, Florida; and E. J. Gutherz, National Marine Fisheries Service, Pascagoula, Mississippi. Although their comments have been incorporated, the authors are responsible for the final versions of the models.

Model Description

Overview. The HSI models for southern and gulf flounders in estuarine habitat are composed of two interacting life requisites, water quality and cover. The larval stage is not considered in the models, because it is spent in marine habitat. Given suitable water quality and cover, food is assumed to be a nonlimiting life requisite for both juveniles and adults. The relationship of habitat variables and life requisites to the HSI is illustrated in Figure 1.

Water quality component. Water quality variables used in the HSI models for both southern and gulf flounders are average annual salinity (V_1), bottom water temperature (V_2), and average minimum dissolved oxygen concentration (V_3).

Salinity (V_1) affects water quality for southern and gulf flounders. Within an estuary, salinity varies depending on the tidal cycle, season, storm events, and long-term climatic trends; therefore, care must be taken in measuring salinity values. Average annual salinity is the preferred measure, since minor variations in salinity are of little consequence to the euryhaline southern flounder. The normal salinity range for juvenile and adult southern flounder in estuaries is 0 to 36 ppt, and the optimal salinity

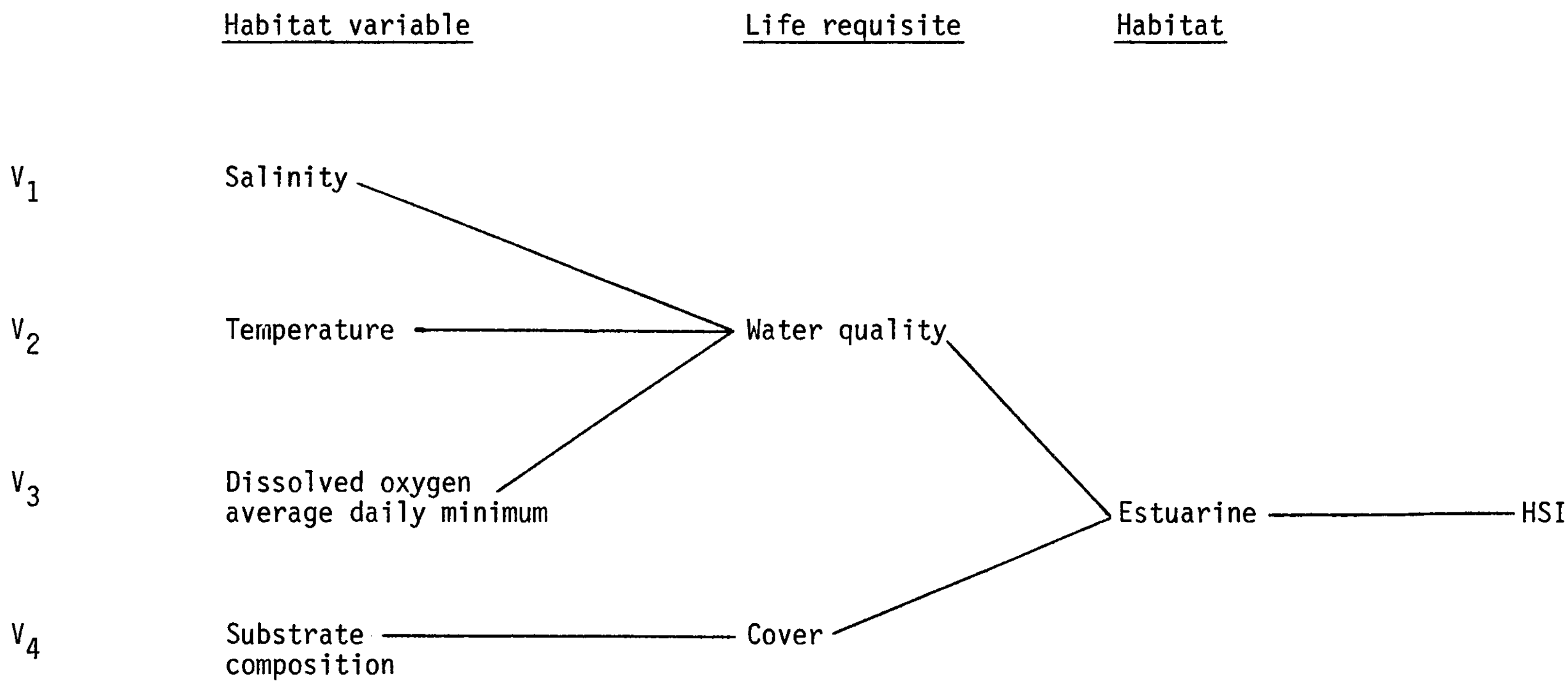


Figure 1. Relationship of habitat variables and life requisites to the habitat suitability index (HSI) for southern and gulf flounders in estuarine habitats.

is assumed to be 5 to 20 ppt. The normal salinity range for juvenile and adult gulf flounders in estuaries is 17 to 36 ppt and the optimal salinity is assumed to be 20 to 35 ppt.

The second variable that determines water quality for flounder is water temperature (V_2). Optimal temperatures for juvenile southern flounder $\leq$ 0.1 g are probably over 30° C (86° F) and decrease as the fish grow older. From May to August, the optimal water temperatures for southern and gulf flounders are assumed to be 20° to 35° C (77° to 95° F).

Dissolved oxygen concentration (V_3) also affects water quality for southern and gulf flounders. The lower lethal limit is probably about 3.0 mg/l and usually occurs only for brief periods in summer. Areas of low dissolved oxygen levels can normally be avoided even by juvenile flounder and do not permanently alter habitat suitability. Juvenile and adult southern flounders have been collected at oxygen levels of 4.0 mg/l.

Cover component. The only cover variable included in the HSI models is substrate composition (V_4). Adult southern flounder are collected most frequently from muddy substrates, and adult gulf flounder from hard or sandy substrates. It is assumed that southern and gulf flounders are responding both to salinity and substrate and that juvenile flounder have substrate preferences similar to those of adults.

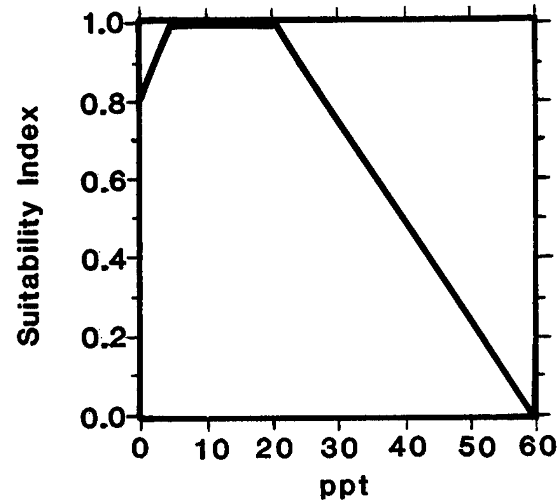
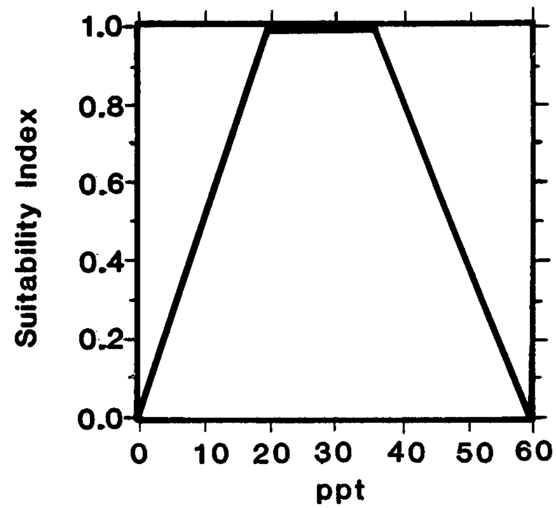
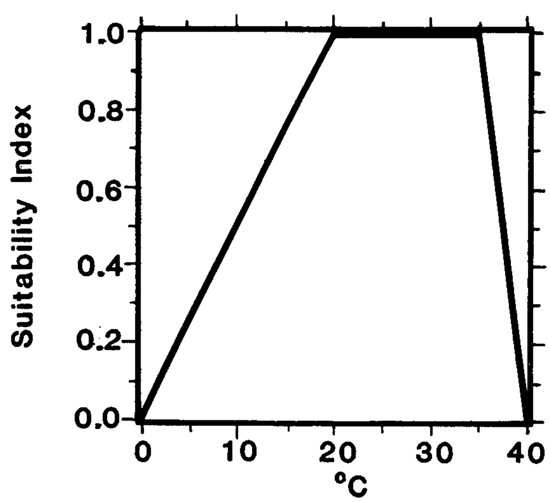
Vegetative cover is not included as a model variable because both southern and gulf flounders are found in densely vegetated tidal marshes, in vegetated and unvegetated bays, and off barren beaches. It is assumed that the presence of flounder in different vegetative cover types is determined primarily by salinity and possibly by substrate. The use of marine grass flats and tidal marshes by juvenile flounder may be related to increased food availability and/or decreased predation.

Water depth is assumed to be unimportant, since both southern and gulf flounders have been collected near shore and in the deepest parts of bays. The preference of juvenile and adult gulf flounders for mouths of estuaries (Williams and Deubler 1968; Powell and Schwartz 1977; Stokes 1977) is assumed to be due to the presence of higher salinities in these localities.

Suitability Index (SI) Graphs for Model Variables

This section presents graphic representations of the relationships between various measurements of estuarine (E) habitat variables and the habitat suitability for southern and gulf flounders. The SI values are read directly off the graph (1.0 = optimum suitability, 0.0 = no suitability) for any variable.

The SI graphs are based on the assumption that the suitability of a particular habitat variable can be represented by a two-dimensional response surface and is independent of other variables that contribute to habitat suitability. Data sources and assumptions associated with documentation of the SI graphs are summarized in Table 1.

Habitat	Variable		Suitability Graph
E	V_{1_S}	Average annual salinity 10 to 15 cm (3.9 to 5.9 inches) above the bottom for southern flounder.	
E	V_{1_G}	Average annual salinity 10 to 15 cm (3.9 to 5.9 inches) above the bottom for gulf flounder.	
E	V_2	Average temperature 10 to 15 cm (3.9 to 5.9 inches) above the bottom for southern and gulf flounders, May to August.	

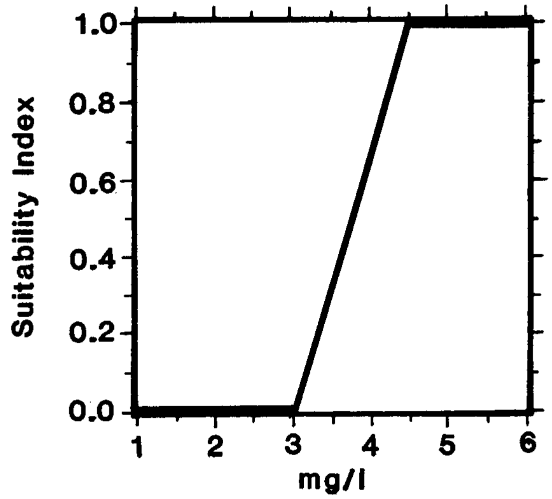
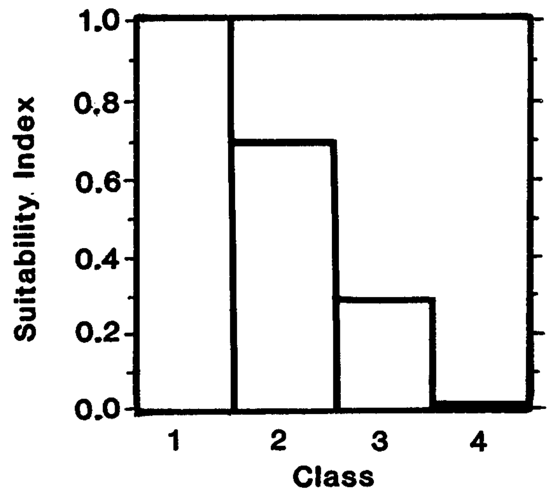
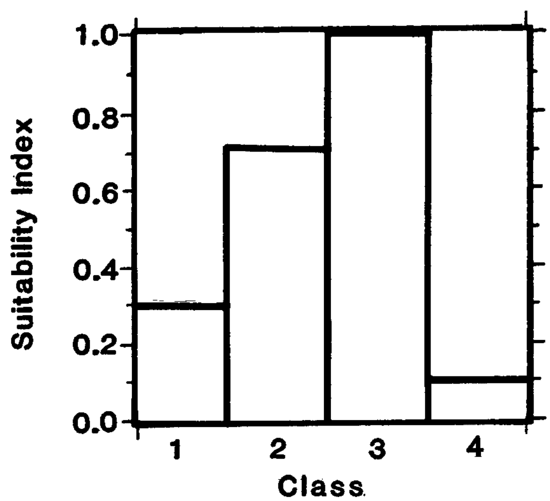
Habitat	Variable		Suitability Graph
E	V_3	Average minimum dissolved oxygen concentration 10 to 15 cm (3.9 to 5.9 inches) above the bottom for southern and gulf flounders May to August.	
E	V_{4_S}	Substrate composition for southern flounder 1) >66% mud, remainder silt or sand 2) 34% to 66% mud or silt, remainder sand or shell 3) < 34% soft sediments, remainder sand or shell 4) Rock or coral	
E	V_{4_G}	Substrate composition for gulf flounder 1) >66% mud, remainder silt or sand 2) 34% to 66% mud or silt, remainder sand or shell 3) <34% soft sediments, remainder sand or shell 4) Rock or coral	

Table 1. Variable sources and assumptions for habitat suitability indices of southern and gulf flounders.

Variable and source	Assumptions
V_{1S} Gunter 1945; Simmons 1957; Williams and Deubler 1968; Perret and Caillouet 1974; Tarver and Savoie 1976; Stokes 1977; Barrett et al. 1978.	Optimal salinities for the growth of southern flounder are those salinities (5 to 20 ppt) at which they are most frequently collected.
V_{1G} Gunter 1945; Reid 1954; Simmons 1957; Springer and Woodburn 1960; Tagatz 1967; Topp and Hoff 1972; Stokes 1977.	Optimal salinities for the growth of gulf flounder are those salinities (20 to 35 ppt) at which they are most frequently collected.
V_2 Gunter 1945; Reid 1954; Springer and Woodburn 1960; Perret 1971; Peters and Kjelson 1975 Stokes 1977; Barrett et al. 1978.	The optimumal temperature for growth and feeding of southern flounder is near 30° C (86° F), and the upper temperature limit is 40° C (104° F). Optimal temperatures for growth and feeding rates of gulf flounder are similar to those for southern flounder since the two species follow similar movement patterns in time and space.
V_3 Deubler and Posner 1963; Hoss and Peters 1976; Barrett et al. 1978.	Southern and gulf flounder are similar to other fish species in having a lower lethal limit of dissolved oxygen near 3 mg/l.
V_{4S} Ginsburg 1952; Stokes 1977; Nall 1979.	Both juvenile and adult southern flounders prefer soft substrates, and the preferences are not totally a product of salinity.
V_{4G} Ginsburg 1952; Springer and Woodburn 1960; Topp and Hoff 1972; Stokes 1977; Nall 1979.	Both juvenile and adult gulf flounder prefer firmer substrates, and the preferences are not totally a product of salinity.

Component Index (CI) and HSI Equations

To obtain an HSI for either southern or gulf flounder in the estuarine habitat, combine SI values for each habitat variable or life requisite.

Because salinity (V_1) appears to be the most important water quality variable for flounder, its SI value is squared in the water quality component equation for southern and gulf flounders. The SI values for water temperature (V_2) and minimum dissolved oxygen (V_3) are not raised to any power in the water quality component equations, since only extreme values are limiting and these are normally avoided and do not permanently alter habitat suitability. The SI value for substrate in both species is equal to the cover component index.

Southern flounder

Component	Equation
Water quality (CI_{WQ})	$((SI_{V_{1_S}})^2 \times SI_{V_2} \times SI_{V_3})^{1/4}$
Cover (CI_C)	$SI_{V_{4_S}}$

Gulf flounder

Component	Equation
Water quality (CI_{WQ})	$((SI_{V_{1_G}})^2 \times SI_{V_2} \times SI_{V_3})^{1/4}$
Cover (CI_C)	$SI_{V_{4_G}}$

The following steps must be taken to determine an HSI for any application.

1. Review the section on model applicability to determine if the model is valid for the intended application.

2. Obtain data for each variable used in the model. Obtain SI values from the SI graphs and calculate component indices by using SI graphs and component index equations.

3. Use the following equation to determine the HSI for either southern or gulf flounder:

$$HSI = (CI_{WQ} \times CI_C)^{1/2}$$

Three estuarine data sets derived from published sources were used in Table 2 to calculate suitability indices, component indices, and habitat suitability index values for southern and gulf flounders. The authors believe that the HSI's calculated from these data sets reflect relative carrying capacities of these areas for flounder.

Table 2. Suitability indices (SI), water quality component indices (CI_{WQ}), cover component indices (CI_C), and habitat suitability indices (HSI) for southern and gulf flounders in three gulf estuaries.

Model component	Old Tampa Bay, FL		Barataria Bay, LA		Upper Laguna Madre, TX	
	Data	SI	Data	SI	Data	SI
			Southern flounder			
V_{1_S}	26 ppt	0.85	20 ppt	1.00	50 ppt	0.25
V_2	30°C	1.00	29°C	1.00	30°C	1.00
V_3	6 mg/l	1.00	6 mg/l	1.00	6 mg/l	1.00
V_{4_S}	Class 3	0.30	Class 1	1.00	Class 2	0.70
CI_{WQ}	0.92		1.00		0.50	
CI_C	0.30		1.00		0.70	
HSI	0.53		1.00		0.59	
			Gulf flounder			
V_{1_G}	26 ppt	1.00	20 ppt	1.00	50 ppt	0.40
V_2	30°C	1.00	29°C	1.00	30°C	1.00
V_3	6 mg/l	1.00	6 mg/l	1.00	6 mg/l	1.00
V_{4_G}	Class 3	1.00	Class 1	0.30	Class 2	0.70
CI_{WQ}	1.00		1.00		0.63	
CI_C	1.00		0.30		0.70	
HSI	1.00		0.55		0.67	

Field Use of Model

Detailed field sampling of habitat variables through time will provide the most reliable and replicable HSI values. One-time sampling of habitat variables is not recommended because the estuarine habitat is subject to large fluctuations in water quality conditions.

The best indication of critical values for many of the habitat variables is assumed to be the mean values derived for appropriate seasons from literature sources. Much of the information necessary for the use of this model is available from published sources or resource agencies. Calculated HSI values are most useful when data are collected in the specific evaluation area. Local fishery biologists should be consulted to ensure that the data sources used accurately reflect habitat conditions in the evaluation area.

Any or all habitat variables may be estimated for preliminary application of this model, but subjective estimates will result in decreased reliability and duplicability of the model. Subjective estimates should be made by experienced professionals and be accompanied by full documentation of the basis on which estimates were made. Suggested methods for measuring the variables are presented in Table 3.

Table 3. Suggested techniques for field measurements of variables used in the southern and gulf flounder HSI models.

Variable	Techniques
V_1	Salinity can be measured by titration or by a refractometer, hydrometer, or conductivity meter (American Public Health Association et al. 1975).
V_2	Bottom water temperatures can be obtained by using either a thermistor or a thermometer and a water sample collected with a water bottle (American Public Health Association et al. 1975).
V_3	Dissolved oxygen can be measured by Winkler titration or with an oxygen meter (American Public Health Association 1975).
V_4	Substrate samples can be obtained with a coring device such as an Ekman corer or a grab such as a Ponar (Buchanan and Kain 1971). Substrate composition can be determined by washing a known weight of substrate through a series of Tyler sieves.

Interpreting Model Outputs

The HSI values produced by both of these models are relative and should be used only for comparison of habitats. If two areas, or the same area at different times, have different HSI values, the area with the higher HSI should be interpreted as having the capacity for supporting more flounder of the species under consideration than the area with the lower HSI value.

A flounder HSI determined by field application of the model may not reflect the actual population density of the species in the habitat being evaluated, since factors other than those related to habitat may be significant in determining population size.

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50272-101

REPORT DOCUMENTATION PAGE

1. REPORT NO. Biological Report 82(10.92)

2.

3. Recipient's Accession No.

4. Title and Subtitle
Habitat Suitability Index Models: Southern and Gulf Flounders

5. Report Date
June 1985

6.

7. Author(s)
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8. Performing Organization Rept. No.

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10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.
(C)
(G)

12. Sponsoring Organization Name and Address
National Coastal Ecosystems Team
Division of Biological Services
Fish and Wildlife Service
U.S. Department of Interior
Washington, DC 20240

13. Type of Report & Period Covered

14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

A review and synthesis of existing information were used to develop habitat models for southern and gulf flounders (*Paralichthys lethostigma*, *P. albigutta*). The models are scaled to produce an index of habitat suitability between 0 (unsuitable) and 1.0 (optimally suitable) for southern and gulf flounder habitat in the Gulf of Mexico from Florida to Texas. Habitat suitability indices are designed for use with the habitat evaluation procedures previously developed by the U.S. Fish and Wildlife Service. Guidelines for application of the models and techniques for measuring model variables are provided.

17. Document Analysis a. Descriptors
Mathematical models
Wildlife
Fishes

b. Identifiers/Open-Ended Terms
Habitat
Habitat suitability index
Impact assessment
Southern flounder
Gulf flounder
Paralichthys lethostigma
Paralichthys albigutta

c. COSATI Field/Group

18. Availability Statement
Unlimited

19. Security Class (This Report) Unclassified

20. Security Class (This Page) Unclassified

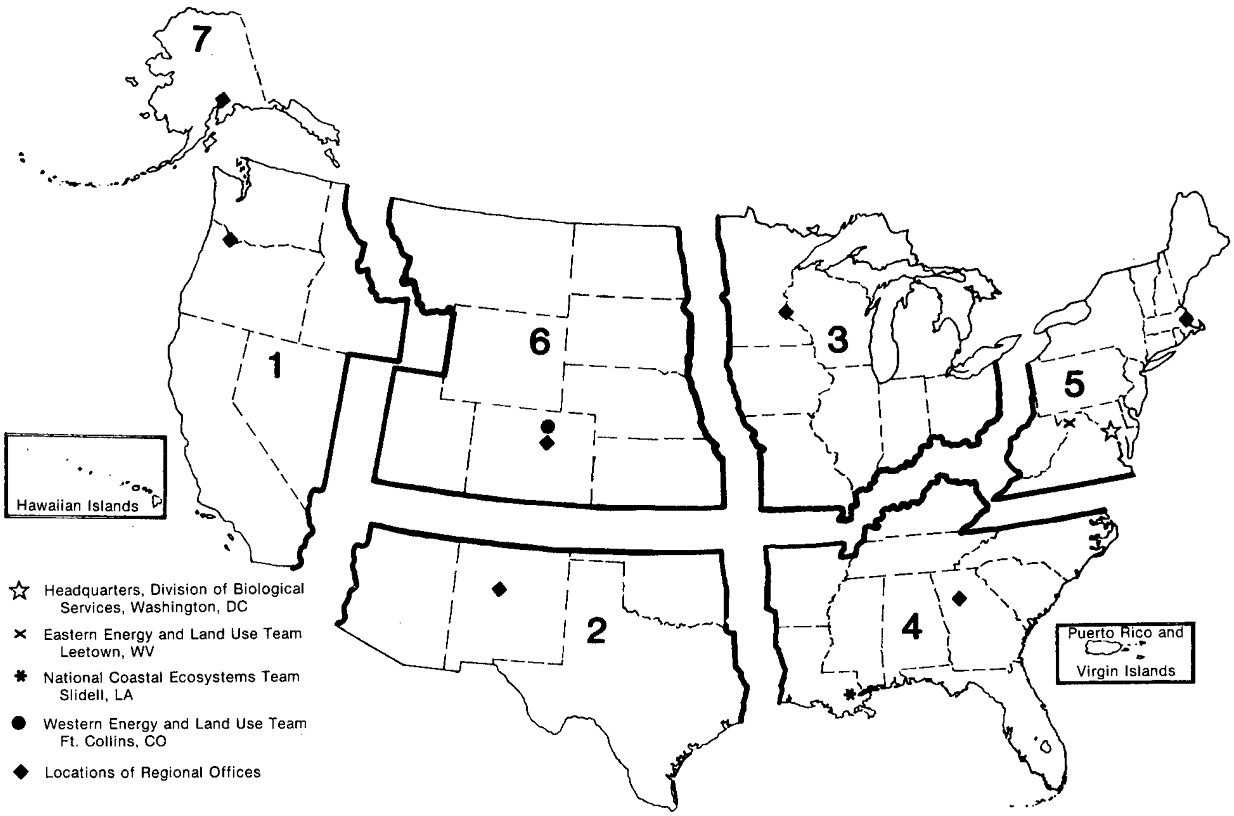
21. No. of Pages vi+ 25

22. Price

(See ANSI-Z39.18)

OPTIONAL FORM 272 (4-77)
(Formerly NTIS-35)
Department of Commerce

☆U.S. GOVERNMENT PRINTING OFFICE: 1985—573-260



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